The Effect of Pressure Difference Control on Hydraulic Stability in a Variable Flow Air Conditioning System

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Abstract: This paper analyzes the effects of different pressure difference control methods on hydraulic stability in a variable flow air conditioning system when it is applied to different air conditioning water systems. According to control method and water system, it can be divided into direct return system pass-by control, direct return system terminal control, reversed return system pass-by control and reversed return system terminal control. The results indicate that reversed return system terminal control has the best hydraulic stability.

Key words: variable flow system; pass-by control; terminal control; hydraulic stability

1.SUMMARY

In fluid conveying system, hydraulic stability (stability for short) refers to that the flow of each pipe section or client changes with the flow of other pipe sections or clients. For example, if the initiative flow decrease or increase of a bypass has great effect on the flow of other bypasses, it means that the system is weak in stability; on the contrary, if the initiative flow decrease or increase of a bypass has little effect on the flow of other bypasses, it means that the system is strong in stability.

In variable flow air conditioning system pressure difference signals are often used to control the adjustment in the frequency-conversion and speed-conversion of pumps. Usually there are two ways to position the place of pressure difference control point: one is to position pressure difference control point on the main backwater supply pipe, usually at both sides of pass-by pipe, and this way of pressure difference signal control is called pass-by control; the other is to position pressure difference control point on the end device of the most unfavorable circuit and both ends of control valve, and this way of pressure difference signal control is called terminal control. The positioning of these two different pressure difference control point has different effect on water system stability. The paper will make an analysis and comparison on stability against two different positioning and the application in both of direct return system and reversed return system.

2.ANALYSIS METHODS

For a pipe network with several bypasses, see figure 1. When close certain bypass, re-calculate the flow of other open bypass and then make analysis for the flow of every bypass with two methods:

1) When close bypass *i*, the ratio between the new flow of bypass *j* and the designed flow $X_{ij}=q'_{ij} / q_{ij}$ is called the comparative flow of bypass *j* when bypass *i* is closed. Obviously the closer X_{ij} is to 1, the better the stability of bypass *j* is compared with the initiative adjustment bypass when bypass I is closed; on the contrary, the farther the worse. When close other bypasses respectively, the ratio between the average deviation of actual bypass *j* flow from designed flow is called the flow stability coefficient of bypass *j*:

$$\overline{X_j} = \sum_{i=1}^{K} \left| X_{i,j} - 1 \right| \Big/ (K-1)$$

In the formula *K* is the number of bypasses in the system. $\overline{X_j}$ value reflects the stability of bypass *j*. The closer $\overline{X_j}$ value is to 0, the more stable bypass *j* is.

2) When bypass i is closed, the ratio between the average deviation of actual bypass j flow from designed flow is called the flow stability coefficient of bypass i:

$$Y_i = \frac{\sum_{j=1}^{i-1}\left|X_{i,j} - 1\right| + \sum_{j=i+1}^{K}\left|X_{i,j} - 1\right|}{K-1}$$

Obviously the closer Y_i value is to 0, the smaller interference to other bypasses the adjustment of bypass i produces, small interference for short. Otherwise the interference is huge.

3) The mean of all bypass $\overline{X_j}$ values $X = \sum_{j=1}^{K}\overline{X_j} \Big/ K$ is called the stability coefficient of the pipe network. Obviously the closer X is to 0, the more stable the pipe network is, otherwise, the less stable.

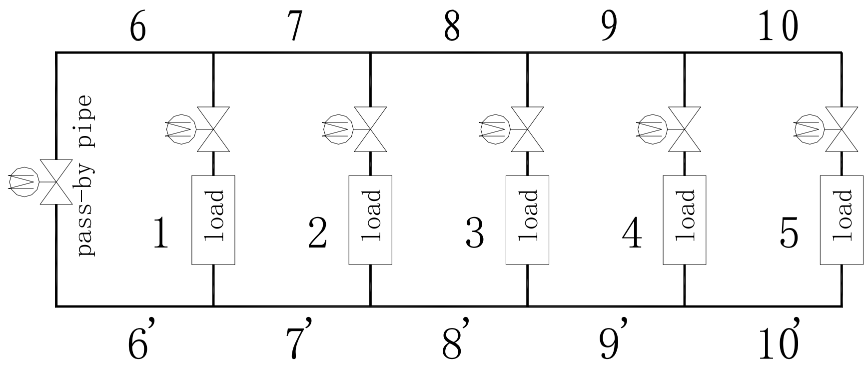

Fig.1 Direct return system

Although the actual flow adjustment usually is to turn up or turn down instead of turn off, but the effect is similar and is comparable.

3.STABILITY ANALYSIS ON DIRECT RETURN SYSTEM PASS-BY CONTROL

Figure 1 shows a direct return system with 5 bypasses, the end devices are of the same type and the designed flow is 4m^3/h. For the resistance of each pipe section and bypass see table 1. After calculation the pressure difference between two ends of by-pass tube is 20.32mH$_2$O which is regarded as the pressure difference set value. Calculate the flow deviation coefficient of other bypasses when close respectively each bypass and then carry out stability and interference analysis. Results are shown in table 2.

Tab.1 Resistance distribution of every pipe section (h^2/m^5)

Pipe section	1	2	3	4	5	6	7	8
S	1.02	0.86	0.68	0.6	0.5	0.005	0.005	0.01
Pipe section	9	10	6’	7’	8’	9’	10’	
S	0.01	0.05	0.005	0.005	0.01	0.01	0.05	

Tab.2 Calculation results of direct return system pass-by control

i \ j	1	2	3	4	5	Y_i
1	0	1.037	1.037	1.037	1.037	0.037
2	1.034	0	1.071	1.071	1.071	0.062
3	1.029	1.062	0	1.130	1.130	0.088
4	1.028	1.059	1.124	0	1.177	0.097
5	1.028	1.059	1.124	1.177	0	0.097
$\overline{X_j}$	0.03	0.054	0.089	0.104	0.104	——

From the calculated results shown in the table the following rules could be inferred:

1) No matter which bypass closes the flow of other bypasses would increase. From water pressure pattern we could see the change trend qualitatively: close one bypass the total resistance of the system would increase, the flow in the main in front of the closed bypass would reduce, and water pressure curve becomes gentle. The effect pressure difference among bypasses in front of the closed bypass increases gradually from the front to the back and the effect pressure difference among bypasses after the closed bypass would also increase.

2) The comparative flow of bypasses after the closed bypass are the same, i.e. the proportion of the flow of each bypass after the closed bypass in the total flow of all bypasses after the closed bypass remains the same which proves that the ratio of every bypass and the total flow is independent with the total flow.

3) $\overline{X}_j$ and Y_i increases gradually from the front to the back indicates that the stability of the front bypass (next to the by-pass pipe) is stronger than that of the back bypass and the inherence in the front bypass is weaker than that in the back.

4.STABILITY ANALYSIS ON DIRECT RETURN SYSTEM TERMINAL CONTROL

After calculation it is known that the pressure difference between the end device of the most unfavorable circuit and the two ends of the control valve is $8mH_2O$ which is regarded as the pressure difference set value. When calculating the respectively closed bypasses, the flow deviation coefficient of other bypasses with stability and interference analysis is shown in table 3.

Tab.3 Calculation results of direct return system terminal control

i \ j	1	2	3	4	5	Y_i
1	0	1	1	1	1	0
2	0.965	0	1	1	1	0.009
3	0.841	0.863	0	1	1	0.074
4	0.873	0.900	0.955	0	1	0.068
5	0.797	0.821	0.872	0.913	0	0.149
$\overline{X}_j$	0.131	0.104	0.043	0.022	0	——

From the calculated results shown in the table the following rules could be inferred:

1) No matter which bypass closes the flow of other bypasses would decrease or remain the same. From water pressure pattern we could see the change trend qualitatively: as the bypass pressure difference on the most unfavorable circuit remains the same, the flow through the bypass is the same, and the pressure difference of pipe section joining the bypass with the anterior bypass is also the same, in the figure it is indicated as the slope coefficient of water pressure curve stay the same. When the flow reduces in pipe sections in front of the closed bypass, the water pressure curve would turn gentle and the bypass flow in front of the closed bypass would reduce, also. The closer to the front, the bigger the decrease of bypass pressure difference is, and the higher the flow deviation coefficient is.

2) $\overline{X}_j$ decreases gradually from the front to the back and the $\overline{X}_j$ of the last bypass reaches the minimum value 0 which indicates that the stability of the front bypasses is weaker than that of the back bypasses. The last bypass is the most stable with a constant flow. While Y_i increases gradually from the front to the back which indicates that the interference to the front bypass is smaller than that to the back. The first bypass has no interference to others while the last bypass has the strongest interference. However, Y_i does not increase constantly from the front to the back and the middle bypasses are subject to the fluctuation of flow interference coefficient. After calculation of the pressure difference of bypass

2, bypass 3 and bypass 4 it could be known that H2=13.76mH_2O, H3=10.88mH_2O, H4=9.6mH_2O, then the pressure difference between bypass 2 and bypass 3 is 2.8mH_2O, the pressure drop between bypass 3 and bypass 4 is 1.28mH_2O, smaller than the former. When the pipe flow changes, the pressure drop change is also larger than the latter. Therefore close bypass 3 has greater effect on bypass2 than close bypass 3 on bypass 3. It could be concluded that pipe section pressure drop has certain effect on pipe network bypasses and reduce pipe network pressure drop may improve the stability and reduce the interference to pipe circuit.

5.STABILITY ANALYSIS ON REVERSED RETURN SYSTEM PASS-BY CONTROL

Reversed return system illustrated in figure 2. To make the effect pressure difference among bypasses roughly the same a pipe circuit is added to consume the additional pressure difference. Figure 2 is a reversed return system with 5 bypasses, the end devices are of the same type and the designed flow is 4m^3/h. For the resistance of each pipe section and bypass see table 4. After calculation the pressure difference between two ends of by-pass tube is 20mH_2O which is regarded as the pressure difference set value. Calculate the flow deviation coefficient of other bypasses when close respectively each bypass and then carry out stability and interference analysis. Results are shown in table 5.

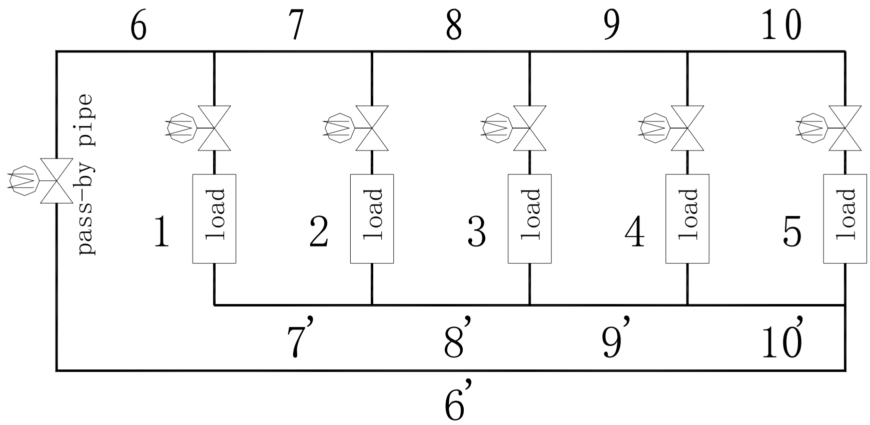

Fig.2 Reversed return system

Tab.4 Resistance distribution of every pipe section (h^2/m^5)

Pipe section	1	2	3	4	5	6	7	8
S	0.5	0.5	0.5	0.5	0.5	0.005	0.0078	0.0139
Pipe section	9	10	6’	7’	8’	9’	10’	
S	0.0312	0.125	0.005	0.125	0.0312	0.0139	0.0078	

Tab. 5 Calculation results of reversed return system pass-by control

i \ j	1	2	3	4	5	Y_i
1	0	1.189	1.106	1.051	1.012	0.090
2	1.164	0	1.146	1.086	1.042	0.109
3	1.087	1.141	0	1.141	1.087	0.114
4	1.042	1.086	1.146	0	1.164	0.109
5	1.012	1.051	1.106	1.189	0	0.090
$\overline{X}_j$	0.076	0.117	0.126	0.117	0.076	——

From the calculated results shown in the table the following rules could be inferred:

1) No matter which bypass closes the flow of other bypasses would increase and the increase is symmetrical, i.e., bypass 1 has the same stability and interference with bypass 5 while bypass 2 and bypass 4 are the same.

2) The stability of each bypass increases from the middle to the two ends. The middle bypass has the weakest stability; the interference to the bypass reduces from the middle to the two ends and the middle bypass is subject to the strongest interference.

6.STABILITY ANALYSIS ON REVERSED RETURN SYSTEM TERMINAL CONTROL

After calculation it is known that the pressure difference between the end device of the most unfavorable circuit and the two ends of the control valve is $8mH_2O$ which is regarded as the pressure difference set value. When calculating the respectively closed bypasses, the flow deviation coefficient of other bypasses with stability and interference analysis is shown in table 6. To make the comparison of calculation easier and remain the symmetry of pipe network, pressure difference control point is set on the middle bypass.

Tab.6 Calculation results of reversed return system terminal control

i \ j	1	2	3	4	5	Y_i
1	0	1.075	1	0.950	0.915	0.053
2	1.016	0	1	0.947	0.910	0.040
3	0.896	0.940	0	0.940	0.896	0.082
4	0.910	0.947	1	0	1.016	0.040
5	0.915	0.950	1	1.075	0	0.053
$\overline{X}_j$	0.074	0.059	0	0.059	0.074	——

From the calculated results shown in the table the following rules could be inferred:

1) $\overline{X}_j$ and Y_i in every bypass are symmetrical, the stability gradually reduces from the middle bypass to the both ends. The bypass with the pressure difference control point is the most stable and the flow is constant. This is caused due to the pressure difference control point. The bypass with the pressure difference control point exerts the strongest interference on other bypasses but the adjacent bypasses exert the weakest interference on others. The interference to bypasses increases along the pipe to the ends, therefore set the pressure difference control point on the middle bypass in order to improve the general stability of the pipe network and reduce the interference of the bypasses.

2) Close a certain bypass most of the flow in other bypasses would reduce. If close more bypasses the flow decrease in others would be greater or even all bypass flow would reduce. The flow increased bypass is present on the bypasses next to the closed bypass and the smaller the *Yi* value of the closed bypass is, the more obvious the flow increase of the adjacent bypass is.

7.CONCLUSION

The hydraulic power stability of the pipe network after calculation of the previous four situations is shown in table 7.

Tab.7 Calculation results of pipe network hydraulic power stability

System type	Direct return system pass-by control	Direct return system terminal control	Reversed return system pass-by control	Reversed return system terminal control
X	0.076	0.060	0.102	0.053

From the calculation results in the table we can see that the pipe network hydraulic power stability order under the four conditions is as follows:

Reversed return system terminal control> Direct return system terminal control> Direct return system pass-by control> Reversed return system pass-by control

The above calculation results indicate that the pipe network hydraulic power stability of terminal control in general is better than that of pass-by control. For variable flow air conditioning system, reversed return system pass-by control shall be given the priority and the pressure difference control point shall be set on the middle bypass and then may consider using direct return system terminal control. When the system cannot realize terminal control, direct return system pass-by control shall be preferred.

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